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TRANSFORMER

The present invention relates to a power transformer comprising at least one high voltage winding and one low voltage winding.

The term "power transformer" as used herein means a transformer having a rated output from a few hundred kVA to more than 1000 MVA and a rated voltage from 3-4 kV to very high transmission voltages, e.g. from 400-800 kV or higher.

Conventional power transformers are described in e.g. A.C.Franklin and D.P.Franklin, "The J & P Transformer Book, A Practical Technology of the Power Transformer", published by Butterworths, 11th edition, 1990. Problems related to internal electric insulation and related topics are discussed in e.g. H.P.Moser, "Transformerboard, Die Verwendung von Transformerboard in Grossleistungstransformatoren", published by H.Weidman AG, Rapperswil mit Gesamtherstellung: Birkhäuser AG, Basle, Switzerland.

In transmission and distribution of electric energy transformers are exclusively used for enabling exchange of electric energy between two or more electric systems. Transformers are available for powers from the 1 MVA region to the 1000 MVA region and for voltages up to the highest transmission voltages used today.

Conventional power transformers comprise a transformer core, often formed of laminated commonly oriented sheet, normally of silicon iron. The core is formed of a number of legs connected by yokes which together form one or more core windows. Transformers having such a core are usually called core transformers. A number of windings are provided around the core legs. In power transformers these windings are almost always arranged in a concentric configuration and distributed along the length of the core leg.

Other types of core structures are, however, known, e.g. so-called shell transformer structures, which normally have rectangular windings and rectangular leg sections disposed outside the windings.

Air-cooled conventional power transformers for lower power ranges are known. To render these transformers screen-protected an outer casing is often provided, which also reduces the external magnetic fields from the transformers.

Most power transformers are, however, oil-cooled the oil also serving as an insulating medium. An oil-cooled and oil-insulated conventional transformer is enclosed in an outer case which has to fulfil heavy demands. The construction of such a transformer with its associated circuit couplers, breaker elements and bushings is therefore complicated. The use of oil for cooling and insulation also complicates service of the transformer and constitutes an environmental hazard.

A so-called "dry" transformer without oil insulation and oil cooling and adapted for rated powers up to 1000 MVA with rated voltages from 3-4 kV and up to very high transmission voltages comprises windings formed from conductors such as shown in Figure 1. The conductor comprises central conductive means composed of a number of non-insulated (and optionally some insulated) wire strands 5. Around the conductive means there is an inner semiconducting casing 6 which is in contact with at least some of the non-insulated strands 5. This semiconducting casing 6 is in turn surrounded by the main insulation of the cable in the form of an extruded solid insulating layer 7. This insulating layer 7 is surrounded by an external semiconducting casing 8. The conductor area of the cable can vary between 80 and 3000 mm^2 and the external diameter of the cable between 20 and 250 mm.

Whilst the casings 6 and 8 are described as "semi-conducting" they are in practice formed from a base polymer mixed with carbon black or metallic particles and have a volume resistivity of between 1 and 10^5 Ω·cm, preferably between 10 and 500 Ω·cm. Suitable base polymers for the casings 6 and 8 (and for the insulating layer 7) include ethylene vinyl acetate copolymer/nitrile rubber, butyl grafted polythene, ethylene butyl acrylate copolymer, ethylene ethyl acrylate copolymer, ethylene propene rubber, polyethylenes of low density, poly butylene, poly methyl pentene, and ethylene acrylate copolymer.

The inner semiconducting casing 6 is rigidly connected to the insulating layer 7 over the entire interface therebetween. Similarly, the outer semiconducting casing 8 is rigidly connected to the insulating layer 7 over the entire interface therebetween. The casings 6 and 8 and the layer 7 form a solid insulation system and are conveniently extruded together around the wire strands 5.

Whilst the conductivity of the inner semiconducting casing 6 is lower than that of the electrically conductive wire strands 5, it is still sufficient to equalise the potential over its surface. Accordingly, the electric field is distributed uniformly around the circumference of the insulating layer 7 and the risk of localised field enhancement and partial discharge is minimised.

The potential at the outer semiconducting casing 8, which is conveniently at zero or ground or some other controlled potential, is equalised at this value by the conductivity of the casing. At the same time, the semi-conducting casing 8 has sufficient resistivity to enclose the electric field. In view of this resistivity, it is desirable to connect the conductive polymeric casing to ground, or some other controlled potential, at intervals therealong.

The transformer according to the invention can be a one-, three- or multi-phase transformer and the core can be of any design. Figure 2 shows a three-phase laminated core transformer. The core is of conventional design and comprises three core legs 9, 10, 11 and joining yokes 12, 13.

The windings are concentrically wound around the core legs. In the transformer of Figure 2 there are three concentric winding turns 14, 15, 16. The innermost winding turn 14 can represent the primary winding and the two other winding turns 15,16 the secondary winding. To make the Figure more clear such details as connections for the windings are left out. Spacing bars 17, 18 are provided at certain locations around the windings. These bars 17, 18 can be made of insulating material to define a certain space between the winding turns 14, 15, 16 for cooling, retention etc. or be made of an electrically conducting material to form a part of a grounding system of the windings 14, 15, 16.

The mechanical design of the individual coils of a transformer must be such that they can withstand forces resulting from short circuit currents. As these forces can be very high in a power transformer, the coils must be distributed and proportioned to give a generous margin of error and for that reason the coils cannot be designed so as to optimize performance in normal operation.

The main aim of the present invention is to alleviate the above mentioned problems relating to short circuit forces in a dry transformer.

This aim is achieved by a transformer as defined in claim 1.

By manufacturing the transformer windings from a conductor having practically no electric fields outside an

outer semiconducting casing thereof, the high and low voltage windings can be easily mixed in an arbitrary way for minimizing the short circuit forces. Such mixing would be unfeasible in the absence of the semiconducting casing or other electric field containing means, and would therefore be considered impossible in a conventional oil-filled power transformer, because the insulation of the windings would not withstand the electric field existing between the high and low voltage windings.

It is also possible to reduce the distributed inductance and design the transformer core for the optimum match between window size and core mass.

According to an embodiment of the invention at least some of the turns of the low voltage winding are each split into a number of subturns connected in parallel for reducing the difference between the number of high voltage winding turns and the total number of low voltage winding turns to make the mixing of high voltage winding turns and low voltage winding turns as uniform as possible. Preferably, each turn of the low voltage winding is split into such a number of subturns, connected in parallel, such that the total number of low voltage winding turns is equal to the number of high voltage winding turns. High voltage and low voltage winding turns can then be mixed in a uniform manner such that the magnetic field generated by the low voltage winding turns substantially cancels the magnetic field from high voltage winding turns.

According to another advantageous embodiment, the turns of the high voltage winding and the turns of the low voltage winding are arranged symmetrically in a chessboard pattern, as seen in cross-section through the windings. This is an optimum arrangement for obtaining an efficient mutual cancellation of magnetic fields from the low and high voltage windings and thus an optimum arrangement for reducing the short circuit forces of the coils.

According to still another advantageous embodiment, at least two adjacent layers have substantially equal thermal expansion coefficients. In this way thermal damages to the winding is avoided.

Another aspect of the invention provides a method of winding a transformer as defined in claim 18.

To explain the invention in more detail, embodiments of the transformer according to the invention will now be described by way of example only with reference to the drawings in which:

Figure 1 shows an example of the cable used in the windings of the transformer according to the invention;

Figure 2 shows a conventional three-phase transformer;

Figures 3 and 4 show in cross-section different examples of the arrangement of the low and high voltage windings of the transformer of the invention; and

Figure 5 shows a method of winding the transformer.

Figure 3 is a cross-section through the portion of the windings of a power transformer according to the invention within the transformer core 22. A layer of a low voltage winding 26 is located between two layers of a high voltage winding 28. In this embodiment the transformation ratio is 1:2.

The direction of the current in the low voltage winding 26 is opposite to the direction of the current in the high voltage winding 28 and the resulting forces from the currents in the low and high voltage winding consequently partially cancel each other. This possibility of reducing the effect of current induced forces is of great importance, especially in case of a short circuit.

Struts 27 of laminated magnetic material, including spacers 29 providing air gaps, are located between the windings 26, 28 for improving transformer efficiency.

Cancellation of short circuit forces can be improved even further by splitting the turns of the low voltage winding into a number of subturns connected in parallel, preferably such that the total number of low voltage turns becomes equal to the number of high voltage winding turns. Thus, if the transformation ratio amounts to e.g. 1:3 each turn of the low voltage winding is split into three subturns. It is then possible to mix the low and high voltage windings in a more uniform pattern. An optimum arrangement of the windings is shown in Figure 4, where low and high voltage winding turns 30 and 32 respectively are arranged symmetrically in a chessboard pattern. In this embodiment the magnetic fields from each turn of the low and high voltage windings 30, 32 substantially cancel each other and short circuit forces are almost completely cancelled.

When splitting a winding turn into a number of subturns the conducting area of each subturn can be reduced correspondingly since the sum of the current intensities in the subturns remains equal to the current intensity in the original winding turn. Thus no more conducting material, (normally copper), is needed when splitting the winding turns, provided that other conditions are unchanged.

Figure 5 schematically shows how the transformer of the invention can be wound. A first drum 40 carries a high voltage conductor 42 and a second drum 44 carries a low voltage conductor 46. The conductors 42, 46 are unwound from the drums 46, 44 and wound onto a transformer drum 48, all three drums 40, 44, 48 rotating simultaneously. Thus the high and low voltage conductors can easily be intermixed. Joints can be provided between different winding layers.

In the transformer of the invention the magnetic energy and hence the stray magnetic field in the windings is reduced. A wide range of impedances can be chosen.

The electrical insulation systems of the windings of a transformer according to the invention are intended to be able to handle very high voltages and the consequent electric and thermal loads which may arise at these voltages. By way of example, power transformers according to the invention may have rated powers in excess of 0.5 MVA, preferably in excess of 10 MVA, more preferably greater than 30 MVA and up to 1000 MVA and have rated voltages from 3 - 4 kV, in particular in excess of 36 kV, and preferably more than 72.5 kV up to very high transmission voltages of from 400 - 800 kV or higher. At high operating voltages, partial discharges, or PD, constitute a serious problem for known insulation systems. If cavities or pores are present in the insulation, internal corona discharge may arise whereby the insulating material is gradually degraded eventually leading to breakdown of the insulation. The electric load on the electrical insulation in use of a transformer according to the present invention is reduced by ensuring that the inner first layer of the insulation system which has semi-conducting properties is at substantially the same electric potential as conductors of the central electrically conductive means which it surrounds and the outer second layer of the insulation system which has semi-conducting properties is at a controlled, e.g. earth, potential. Thus the electric field in the solid electrically insulating layer between these inner and outer layers is distributed substantially uniformly over the thickness of the intermediate layer. By having materials with similar thermal properties and with few defects in these layers of the insulation system, the possibility of PD is reduced at given operating voltages. The windings of the transformer can thus be designed to withstand very high operating voltages, typically up to 800 kV or higher.

Although it is preferred that the electrical insulation should be extruded in position, it is possible to build up an electrical insulation system from tightly wound, overlapping layers of film or sheet-like material. Both the semiconducting layers and the electrically insulating layer can be formed in this manner. An insulation system can be made of an all-synthetic film with inner and outer semiconducting layers or portions made of polymeric thin film of, for example, PP, PET, LDPE or HDPE with embedded conducting particles, such as carbon black or metallic particles and with an insulating layer or portion between the semiconducting layers or portions.

For the lapped concept a sufficiently thin film will have butt gaps smaller than the so-called Paschen minima, thus rendering liquid impregnation unnecessary. A dry, wound multilayer thin film insulation has also good thermal properties.

Another example of an electrical insulation system is similar to a conventional cellulose based cable, where a thin cellulose based or synthetic paper or non-woven material is lap wound around a conductor. In this case the semiconducting layers, on either side of an insulating layer, can be made of cellulose paper or non-woven material made from fibres of insulating material and with conducting particles embedded. The insulating layer can be made from the same base material or another material can be used.

Another example of an insulation system is obtained by combining film and fibrous insulating material, either as a laminate or as co-lapped. An example of this insulation system is the commercially available so-called paper polypropylene laminate, PPLP, but several other combinations of film and fibrous parts are possible. In these systems various impregnations such as mineral oil can be used.